case the ratio of 454 to 294, or, roughly, of 3 to 2. Thus, with these assumptions, the density in the wave-front is half as great again as the density of the undisturbed air. The wave resembles that caused by an explosion rather than that due to an ordinary sound.

Several attempts were made to see the train of waves due to a musical note, but on consideration of the facts just stated it is not surprising that they were all unsuccessful. The notes due to a shrill whistle and to a siren blown by a pair of foot bellows were both ineffective.

An attempt was also made to obtain a train of waves from the oscillatory discharge of a condenser through a circuit possessing self-induction. A large Leyden jar and a coil of wire were inserted between the main terminals in Fig. 2. The frequency of the oscillation lay between the limits 7920 and 1800 vibrations per second, the wave-length of the corresponding sound-wave lying between 1·3 and 7·3 inches.

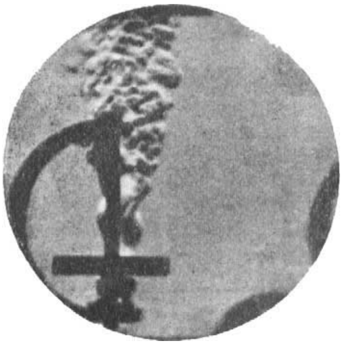

Fig. 4.

A number of photographs were obtained in which the first wave-front had travelled to such a distance that the second wave should have been clear of the terminals. But in none of them is any trace to be seen of a second wave. Thus, as an attempt to photograph a train of waves, this method too proved a failure.

Even as a failure the result is not without its interest, as it brings out very clearly the difference in character between the first discharge and the surgings that follow it when the spark is an oscillatory one.

In the words of Prof. Trowbridge, who has made a special study of oscillatory discharges:—"Photographs of powerful electric sparks lead one to conclude that a discharge of lightning makes way for its oscillations by first breaking down the resistance of the air by a disruptive pilot spark—through the hole thus made in the air the subsequent surgings or oscillations take place."

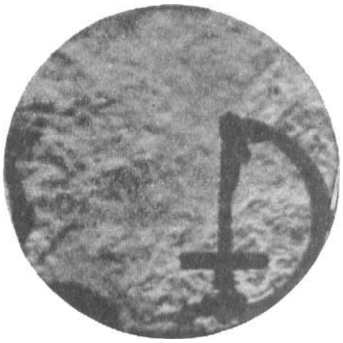

Fig. 5.

In the language of the modern ionic theory this would be interpreted by saying that the first disruptive discharge results in the production of a large number of free ions, and these ions offer an easy passage to the subsequent oscillations.

Since the refractive power of a gas is proportional to its density, and that in turn depends on the temperature, the method will reveal the presence of any region in the air whose temperature differs materially from that of the surrounding atmosphere. Such a case arises in every flame; the products of combustion rise from the flame as a column of heated gas, and this is revealed to the eye as a pillar of fire, or in the photograph as a pillar of cloud. The photograph shows the effect due to the flame of a spirit lamp (Fig. 3).

In order to impress the fact that what is here seen is not the flame, but the heated gas rising from the flame, a small fan was arranged which could be set in rapid rotation and so drive the hot gas all over the field of view (Fig. 4). The photograph (Fig. 5) shows the effect when it has been set rotating.

The flame of a Bunsen burner gives rise to a disturbance similar to that due to the spirit lamp, but more voluminous in character. The peculiar spiral form in which the column of gas rises before breaking up into a cloud is very noticeable in some of these photographs of flames.

A number of photographs were taken of jets of gas issuing from a narrow orifice. In one case the jet is formed by blowing heated air through a brass tube; in another it consists of carbonic acid gas issuing from the generating flask. In consequence of its great density, the gas begins to fall downwards soon after leaving the nozzle.

Several photographs were taken to show the mode of formation of a vortex ring of heated air. These rings were produced in the usual way by means of a box with an aperture in one side, and the opposite side formed of some elastic material. On giving this side a sharp tap, some of the enclosed air rushes out with the formation of a ring. In this case the air in the box was heated by placing a spirit lamp inside it so that the rings, being formed of hot air instead of smoke, were quite invisible save by the use of the method of striæ. Some of these photographs are reproduced in the paper and are very instructive as showing the way in which the vortex motion is produced. The air appears first of all to issue from the orifice in the form of a column, but the tail is gradually left behind while the whirlpool motion of the head is accentuated. Finally, little is to be seen but the section of the ring itself, the spiral structure being strongly marked (Fig. 6). In some cases a circular, in others an elliptic orifice was used.

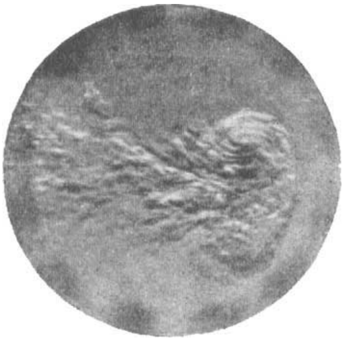

Fig. 6.

The appearance of some of these photographs showing vortex motion strongly recalls the published photographs of the nebulæ of the heavens.

THE TEMPERATURE OF INVERSION OF THE JOULE-KELVIN EFFECT FOR HYDROGEN.[1]

In the year 1854 it was proved by Joule and Lord Kelvin that hydrogen on free expansion behaved differently to all other gases. Air, when allowed to expand from a higher to a lower pressure without performing external work, became cooled, the fall of temperature being proportional to the difference of pressure; hydrogen, on the other hand, became warmer. As is well known, the Joule-Kelvin effect has been applied by Hampson and Linde to the liquefaction of air in quantity, but since for hydrogen the effect is of opposite sign, it was obvious that the Hampson-Linde apparatus could not be directly applied to the liquefaction of that gas ; a conclusion which is confirmed by this research. There seemed no doubt,[1] however, that after due modification the Hampson-Linde method would be applicable to the liquefaction of hydrogen, the necessary condition being that the gas should be cooled to below the temperature at which the Joule-Kelvin effect changes sign before entering the regenerator coil of the apparatus. Below this temperature the gas would become cooled on free expansion ; as in the case of air in the ordinary Hampson apparatus, the cooling would be progressive and, were the heat insulation sufficiently perfect, would result in the partial liquefaction of the gas.

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[1] By K. Olszewski. Translated from the *Bulletin* de l'Académie des Sciences de Cracovie. (December, 1901.)

As is well known, Dewar and Travers (*Phil. Mag.*, 1901) have both succeeded in applying this principle to the production of liquid hydrogen. Both investigators employed as a preliminary refrigerant liquid air boiling under reduced pressure, and by this means cooled the hydrogen to – 200° C. The question now arises as to whether this is really necessary, or whether it would not be possible to liquefy hydrogen by allowing it to undergo free expansion after cooling it to a temperature less difficult to attain. The following investigation was undertaken in the hope of throwing some light on the subject and of determining the temperature at which the sign of the Joule-Kelvin effect changes.

Witkowski (*Roz. pr. Akad. krak.*, W.M.P. xxxv. 247 ; *id.* 1898) has applied two methods to the calculation of this temperature. The first method, based on the theory of corresponding states, gave – 46° C. as the temperature ; the second method, in which Rose-Innes' formula was applied to the extrapolation of Joule and Lord Kelvin's experimental values at temperatures between 0° and 100° C., gave – 79°·3, a result which is nearer to that obtained by me experimentally, viz. – 80°·5. Rose-Innes' formula (*Phil. Mag.* [5], xlv, 228),

$$e = \frac{\alpha}{T} - \beta,$$

is purely empirical, but employing 64·1 and 0·331 as values for the constants, it reproduces the experimental results with remarkable accuracy.

Description of the Apparatus.

The hydrogen employed in these researches was obtained by the action of pure dilute sulphuric acid on commercial zinc ; the gas was purified by passage through solutions of caustic soda and potassium permanganate, and finally through a tower containing pumice-stone soaked in mercuric chloride solution. The gas was collected in a zinc gasometer capable of holding 1200 litres, and from this was taken directly into the Whitehead torpedo-compressor, and compressed at 180 atmospheres into a steel cylinder of 13 litres capacity ; in this cylinder was suspended a wire net containing sticks of caustic potash. During these operations every care was taken to remove all traces of air from the apparatus.

The expansion apparatus is shown in the accompanying figure. The steel cylinder, which contains the hydrogen under pressure, communicates by means of a copper tube with a manometer and with the tube *a* of the apparatus. The tube *a* is bent into a spiral *b*, which terminates in a valve *c*. The valve consists of a jet enclosed within a steel tube, perforated at the sides for the escape of the gas, which serves as a support for it. The valve spindle *d* passes through a gland packed with asbestos at *o*, and is screwed below *o* to fit the opening through which it passes, so as to allow of the valve being opened or closed. The valve is enclosed in a thin metal box *hh*, which is lined with chamois leather ; the gas can escape by a tube *pi*, through the vertical portion of which an electric resistance thermometer is introduced. This instrument has previously been employed in the determination of the critical and boiling points of hydrogen (*Phil. Mag.* [5], xxxix. 199 ; xl. 202) ; the electrical connections are made by means of binding screws at *f* and *g*.

So as to be able to surround the coil *b* and the metal box enclosing the jet and thermometer with different refrigerants, the metal cap *nn* is cemented to the top of a thick-walled glass vessel *ll*. This in turn contains a thin glass vessel *mm*, insulated from the former at the top and bottom.

The refrigerating substances, liquid air, liquid ethylene, and solid carbonic acid and ether, can be introduced into *mm* through a T-tube passing through the cover of the apparatus, and by connecting one branch *k* with an exhaust pump the substance can be evaporated under reduced pressure and the temperature varied considerably. The temperature of the coil and jet can be roughly determined from the readings of a mercury manometer attached to the apparatus.

Method of Experiment.

The first experiments were made at about – 190° C., the temperature of liquid air. The initial pressure on the hydrogen was about 170 atmospheres, and on opening the valve for about five seconds a considerable cooling took place, the beam of the galvanometer attached to the electric thermometer moving 200 mm. over the scale. Using as a refrigerant liquid ethylene boiling at – 003° C., and with an initial pressure on the hydrogen of 150 atmospheres, cooling took place when the valve was opened, but to a less extent, the ray from the galvanometer moving only 30 mm. This was taken to indicate that the temperature of inversion lay considerably above – 100° C., and a series of experiments was next made about the temperature of solid carbonic acid and ether.

In this series twenty-five experiments were made, starting in each case with a temperature of – 78° C. and an initial pressure of between 117 and 110 atmospheres. To regulate the expansion, a small steel cylinder of 0·6 litre capacity was introduced between the main cylinder and the tube *a* ; by filling the small cylinder from the main cylinder and closing the communication between the two before each expansion, the quantity of gas which escaped from the valve, and consequently the temperature change, was always the same. It appeared from these experiments that at – 78° hydrogen becomes warmer on free expansion, but only very slightly so, the ray from the galvanometer moving 3 mm. over the scale.

By reducing the pressure on the carbonic acid by careful pumping, the temperature was slowly reduced. At – 83°, decided cooling took place on expansion, the galvanometer beam moving 5 mm. over the scale. By numerous trials it was found that the temperature at which the Joule-Kelvin effect became zero appeared to be at about – 80°·5 C.

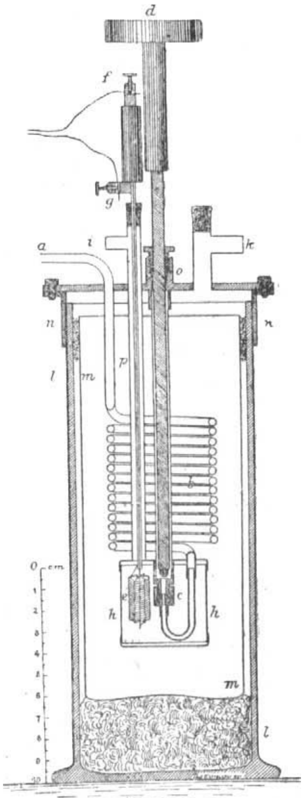

FIG. 1.

Conclusions.

From these experiments it appears that the temperature of the inversion of the Joule-Kelvin effect for hydrogen lies about – 80°·5 C., a number which agrees very closely with that arrived at by Witkowski from the Rose-Innes equation (– 79°·3). This agreement makes it worth while considering the further application of this equation to other substances, particularly to air, and the application of the results to the calculation of the critical temperature of hydrogen on the basis of the theory of corresponding states. We have the following data :—

	Temperature of inversion of Joule-Kelvin effect.	Critical temperature.
Air	633° Abs.	133° Abs.
Hydrogen	192°·5 Abs.	—

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[1] Kammerlingh Onnes (Leyden *Communications*, xxiii. 1896, 16) pointed out the possibility of liquefying hydrogen by means of Linde's apparatus, and stated the conditions, based on the theory of corresponding states, under which liquefaction can occur.

From this it follows that the critical temperature of hydrogen is 40°·4 or −232°·6 C., which is not far from the value which was found for it experimentally, viz. −234°·5 C. (*loc. cit.*).

From these researches it also appears that it is possible to liquefy hydrogen by the method of free expansion without cooling the gas to −200° C. Provided the heat insulation were sufficiently perfect, it should be necessary to cool the apparatus only to −100°, a temperature which could be attained by means of solid carbonic acid evaporating under reduced pressure, before allowing the hydrogen to expand.

M. W. T.

THE RADIANT POINT OF THE APRIL LYRIDS.

The moon being full on the evening of April 22 this year there is little prospect that the shower of Lyrids will assume prominence as a visible spectacle. It should, however, be carefully looked for on the night following April 21, for, notwithstanding the bright moonlight, it is probable that a few fine Lyrids may be observed if the weather is clear. The maximum formerly occurred on April 20, but 1900 not having been a leap year, the epoch of the shower has advanced one day, and must be looked for on April 21.

There is strong evidence to show that the radiant, like that of the Perseids, moves eastwards with the time, but the Lyrid display is always short-lived and frequently of very feeble character. Moreover, cloudy weather sometimes hides the meteors, or moonlight may practically obliterate them, so that it is extremely difficult to determine the exact place of the radiant on several succeeding nights. The April meteors are rarely as abundant as the August Perseids, though there is always the possibility of a brilliant return of the former as in 1803, when they fell so plentifully that they could not be counted.

I have collected together all the determinations of the Lyrid radiant which I have met with during the last nine years, and they form a curious medley of positions from which it seems impossible to derive any very exact results:—

Date.	Radiant.	Meteors.	Observer.
1893 April 20	257° +46°	47	A. A. Nijland, Utrecht.
	271 +42		
	278 +39		
	292 +39		
April 20–21	267 +37	15	H. Corder, Bridgwater.
	276 +34	10	
April 20–21	266 +37	—	E. R. Blakeley, Dewsbury (reduced by Corder).
	276 +34		
April 20–21	265 +34	—	F. H. Ferrington, Shrewsbury (reduced by Corder).
	275 +32		
April 20	272 +33	7	W. F. Denning, Bristol.
21	273 +33	8	
1895 April 13–27	268 +45	20	H. Corder, Bridgwater.
	270 +29		
	274 +33		
	285 +32		
April 19	269 +37	9	E. R. Blakeley, Dewsbury.
21	274 +36	8	
23	280 +35	4	
1896 April 17–21	263½ +40	8	A. A. Nijland, Utrecht.
	271 +36	14	
April 18–19	271 +36	5	H. Corder, Bridgwater.
	284 +32	—	
April 10–22	275 +38	6	A. S. Herschel, Slough.
1898 April 20	271 +36	22	A. A. Nijland, Utrecht.
	280 +27	13	
April 21–24	272 +41	9	
April 19	268 +36	4	E. R. Blakeley, Dewsbury.
April 19–21	268 +25	5	J. H. Bridger, Farnborough.
April 21–22	273½ +32½	12	W. E. Besley, London.
April 12–22	270 +40	5	A. S. Herschel, Slough.
April 20	268 +37	7	J. A. Hardcastle.
1899 April 19	253° +13°	5	A. A. Nijland, Utrecht.
	277 +39	6	
1900 April 20–21	273 +34	8	J. H. Bridger, Farnborough.
April 20–21	266 +26	5	A. King, Leicester.
	274 +33	8	
April 18–24	268 +38	14	A. A. Nijland, Utrecht.
	277½ +40	19	
	302 +54	8	
April 16–21	255 +37	12	A. S. Herschel, Slough.
	255 +27		
	275 +35	23	
1901 April 18–23	266 +30	30	A. S. Herschel, Slough.
	271 +30		
April 12–22	268 +28	32	J. C. W. Herschel, Cambridge.
	273½ +28		
	274½ +33½		
	278 +31		
	278 +37		
	280 +33½		
April 18	266 +33	4	W. F. Denning, Bristol.
April 21	270 +33	25	
April 18–21	261 +36	8	

It will be noticed that some of the observers give a multiple radiant, but that the individual positions compared from year to year do not present a good agreement. At Bristol the radiant has usually been very sharply defined, when the true Lyrids have been sifted from the large number of other meteors directed from showers in nearly the same region of the heavens. The position of the radiant on April 20–21 is at 271° + 33°, and presents a perfect agreement with the radiant point of Comet I 1861, with which the Lyrids have long been supposed to be associated.

Some of the positions included in the list represent showers in Hercules and other contemporary streams. Mr. J. C. W. Herschel, from his observations in 1901, regards the radiant as decidedly multiple, but I believe that further observation will negative this conclusion. There are a considerable number of other meteoric systems in play at the same epoch as the Lyrids, and these, combined with unavoidable errors of observation, must sometimes give rise to apparently scattered radiation and multiple radiants.

W. F. Denning.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

At the annual graduation ceremonial of the University of Edinburgh on April 11, Prof. MacGregor, who delivered an address, stated that the suggestion to found a laboratory in memory of the late Prof. Tait had taken practical shape, and that a subscription of 1000*l.* towards this object had been received from an anonymous donor.

Scarcely a week passes without the announcement in *Science* of generous gifts to institutions for higher education in the United States. The following are among the gifts recorded during the past few weeks:—Mr. J. D. Rockefeller has given 1,000,000 dollars toward the general endowment fund of the University of Chicago, and 250,000 dollars for the general needs of the University during the present academic year. He promised a gift to the Harvard Medical School of 1,000,000 dollars on the condition that 765,000 dollars were collected to meet the sum required for the removal and rebuilding of the school. About 600,000 dollars were subscribed in two weeks, and this was quickly increased to 821,225 dollars, which was more than sufficient to make Mr. Rockefeller's gift available. Mrs. Collis P. Huntington has given 250,000 dollars to the Harvard Medical School to erect a laboratory of pathology and bacteriology in memory of the late Mr. Huntington. Mr. J. Stillman has given 100,000 dollars for the establishment of a chair of anatomy in the same school. Mr. Rockefeller has given 5000 dollars to Washington and Lee University, thus completing the fund of 100,000 dollars for a memorial to the late President William L. Wilson, in the form of an endowment for the chair of economics and political science. Barnard College, Columbia University, has added 500,000 dollars to its endowment, one half having been given by Mr. Rockefeller and the other half having been collected as a condition of this